Development of Methods to Estimate the Seismic Source Model for Prediction of Broadband Strong Ground Motions

Background

The prediction of strong ground motion plays a great role in earthquake mitigation or improvement of seismic design. In particular evaluation of source process generating seismic waves in the frequency range higher than 1 Hz, which corresponds with the dominant frequencies for many artificial structures, is one of the most important issues. However, since it is difficult to directly treat such high-frequency ground motions in applying the conventional source inversion scheme, the characteristics of high-frequency radiation have been indirectly estimated through the source model derived from lower-frequency ground motion records. Therefore development of a new inversion technique is required in order to estimate the detailed source rupture process using broadband strong-motion records including important frequency range for engineering purpose. Moreover the statistical characteristics of main source parameters for strong-motion generation, such as the spatial distribution of slip and effective stress should be derived from the estimated source process.

Objectives

To develop a new inversion technique in order to estimate source rupture process that can reproduce observed strong - motion records, and to confirm its applicability by using broadband strong-motion simulation.

Principal Results

1. Development of source inversion method using the empirical Green's function method and very fast simulated annealing

In order to directly estimate the area where high-frequency strong motions are generated on the seismic fault, we developed new inversion technique by combining the empirical Green's function method (EGFM) for minute estimation of the seismic response from the source to the station, and the very fast simulated annealing (VFSA) for efficient search of the optimal solution. The numerical tests demonstrated that the developed method can find the source model much closer to the optimal one with less computational costs, compared with other search algorithms (Fig.1).

2. Application to the actual strong-motion records

The developed method was applied to the observed strong-motion records from the 1997 Izu-Hanto Toho-Oki earthquake (M5.9), observed at bedrock stations installed by CRIEPI (Fig.2). Analyzed frequency range during the inversion was extended to 5 Hz, though conventional methods can treat signals in the frequency range up to around 1 Hz. The derived source models reproduce the observed velocity ground motions very well (Fig.3). The new method makes it possible to perform the independent and simultaneous estimation for the spatial distributions of seismic moment, which controls the low-frequency wave radiation, and that of effective stress, which provides the generation of high-frequency waves. In the case of our analyzed event, it was revealed that both the low-frequency and high-frequency waves are strongly radiated from nearly same area on the fault plane since both show similar spatial distributions (Fig.4).

Furthermore we constructed the source model for the strong-motion prediction by deriving the statistical feature of the moment and the effective stress distributions, and verified its applicability from the broadband strong-motion simulation.

Future Developments

The developed method will be applied to strong-motion data from larger earthquakes in order to clarify the mechanisms of high-frequency and low-frequency seismic wave radiations from the source. Then advanced scheme of strong-motion prediction reflecting the detailed source rupture process will be proposed. Further the seismic design will be improved by providing more suitable input motions based on the predominant period for each main structure.

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Reference

Y. Shiba, 2004, "Study on Rupture Process by Waveform Inversion Using Simulated Annealing and Simulation of Broadband Ground Motions", CRIEPI Report N04006.

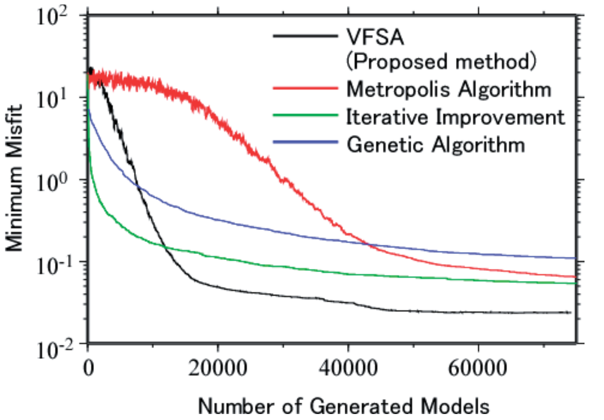


Fig.1 Comparison of minimum misfits in different search algorithms

Each method is combined with the empirical Green's function method.

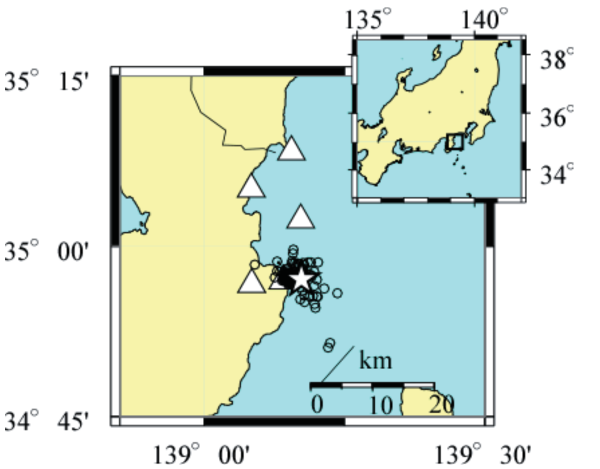


Fig.2 Distribution of epicenters for the target event (star) and its aftershocks (circles), with the observation stations (triangles)

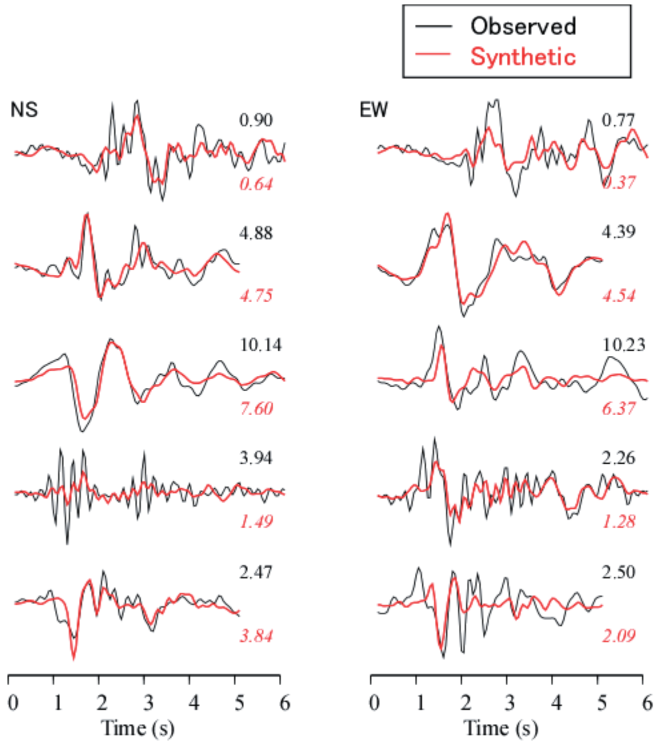
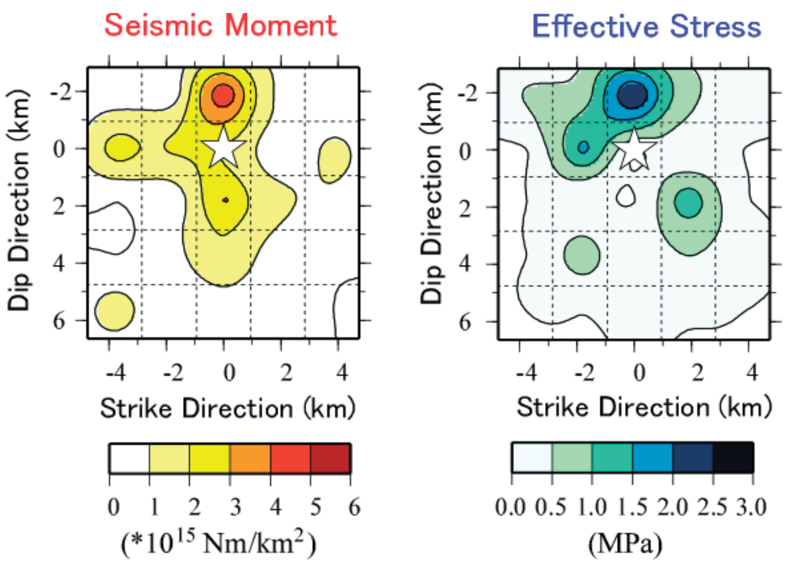


Fig.3 Comparison between synthetic and observed waveforms

Analyzed frequency band ranges from 0.4 to 5 Hz. Numbers above and below the waves respectively show the peak values of observed and synthetic motions.



The seismic fault is divided into 25 sub-faults and the optimal values are searched at each area. For both parameters the peak area is located in the shallow regions just above the hypocenter.

Fig.4 Distributions of the estimated seismic moment (left) and effective stress (right) on the seismic fault